Interreg
Danube Region

Co-funded by
the European Union

Danube Water Balance

Development of a harmonized water balance modelling system for the Danube River Basin

OVF GENERAL DIRECTORATE OF WATER MANAGEMENT

This project is supported by the Interreg Danube Region Programme co-funded by the European Union.

Lead Partner:
General Directorate of Water management of Hungary (OVF)
Márvány street 1/D. 1012 Budapest

DANUBE WATER BALANCE MAIN FIGURES

The Danube Water Balance (Development of a harmonized water balance modelling system for the Danube River Basin) project was approved for co-financing within the Interreg Danube Region, under the Programme Priority 2: A greener, low-carbon Danube Region. With a total budget of 3,028,319.50 €, co-funded by Interreg Funds, the project aimed to achieve the Programme priority specific objective 2.3: Sustainable, integrated, transnational water and sediment management in the Danube River Basin ensuring good quality and quantity of waters and sediment balance.
The Danube Water Balance project started on 01 January 2024 and lasted until – with a 3 months long prolongation – 30 September 2026. The project was divided into 6 periods, 5 periods lasted 6 months long and the last period lasted 3 month.

Project Partner Institution	Country
General Directorate of Water management	Hungary
Budapest University of Technology and Economics	Hungary
Vienna University of Technology	Austria
International Institute for Applied Systems Analysis	Austria
Brno University of Technology	Czech Republic
Slovak University of Technology in Bratislava	Slovakia
Slovenian Environment Agency	Slovenia
Croatian Waters	Croatia
Institute for Water Management	Bosnia and Herzegovina
University of Sarajevo	Bosnia & Herzegovina
University of Novi Sad	Republic of Serbia
Jaroslav Černi Water Institute	Republic of Serbia
Public Water Management Company „Srbijavode“	Republic of Serbia
National Institute of Hydrology and Water Management	Romania
National Administration Romanian Waters	Romania
National Meteorological Administration	Romania
Executive Agency “Exploration and Maintenance of the Danube River	Bulgaria
National Institute of Meteorology and Hydrology	Bulgaria
Bulgarian Water Association	Bulgaria
Center for Strategic Environmental Studies	Moldova

Table I: Project partnership

The Danube Water Balance project is organised around three specific objectives (SO1, SO2 and SO3) aimed at achieving the project objectives through the implementation of planned activities, and their corresponding deliverables and outputs. The leader for Specific objective 1 (SO1), titled 'Enhanced joint data management for Danube River Basin water management planning' was National Institute of Hydrology and Water Management (Romania). The leader for Specific objective 2 (SO2), titled 'A Jointly developed water balance tool for the Danube River Basin' was International Institute for Applied Systems Analysis. The leader for Specific objective 3 (SO3), titled 'Fostering mutual acceptance of joint water balance methodology through capacity building' was Public Water Management Company „Srbijavode".
The document below is a summary of the outputs developed during the project. To access the full versions of the outputs, please visit the project's official website: https://interreg-danube.eu/projects/danube-water-balance

GENERAL SUMMARY

The Danube River Basin is one of the most international and diverse river basins in the world. Spanning 14 countries, it connects millions of people, intricate ecosystems, and vital economic sectors. However, this shared lifeline is facing unprecedented pressures. In recent years, the impacts of climate change have manifested across the region in the form of severe droughts, prolonged dry periods, and extreme hydrological shifts. These challenges transcend national borders, demanding a unified, evidence-based response to ensure long-term water security and sustainable resource management.
For decades, water quantity management across the Danube Basin has been constrained by fragmented data, national-level methodologies, and inconsistent calculation frameworks. While individual countries have maintained robust national monitoring systems, the resulting sub-regional "mosaics" have hindered a holistic understanding of the basin-wide water balance. To bridge these gaps, the Danube Water Balance project was launched under the Interreg Danube Region Programme.

The challenge: understanding water balance at basin scale

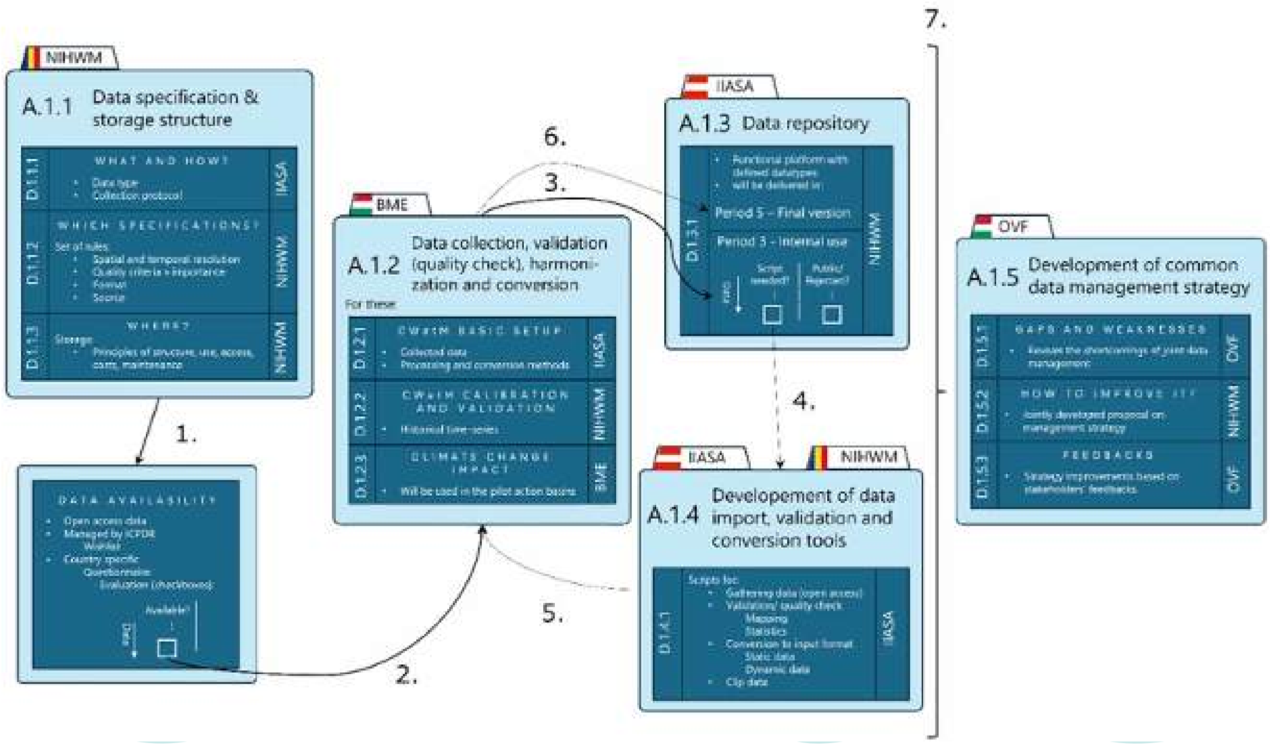
Water resources in the Danube Basin are shaped by processes that operate across national, sectoral and hydrological boundaries. Precipitation, evapotranspiration, runoff, groundwater processes, abstraction and water demand interact in space and time. A change in one part of the system can affect water availability elsewhere.
This creates a practical challenge for water managers. Relevant information is often held by different institutions, collected according to different methodologies and stored in different formats. Even where data are available, they may not be directly compatible with a common modelling framework. Transboundary modelling therefore requires not only technical capacity, but also agreed approaches to data preparation, sharing, access and interpretation.
The challenge is further intensified by climate change. Changes in precipitation and temperature patterns can alter runoff generation and groundwater recharge, while increasing demand in agriculture, public water supply, industry and other sectors can add pressure during periods when water is already scarce. Low-flow conditions are particularly important because they can coincide with high water demand and reduced ecological resilience.
The DWB approach combines four mutually reinforcing elements: harmonised data, basin-scale modelling, accessible visualisation and knowledge exchange. The objective was not simply to produce another modelling exercise, but to establish a common technical and institutional basis for future cooperation.
This integrated approach is reflected in the project's outputs: a data management infrastructure and strategy, a common modelling framework, climate impact assessments, interpretation and visualisation tools, training materials, stakeholder engagement products and recommendations for the future development of the model towards a stronger water-management application.

Harmonized Data Repository of Environmental, Hydrological and Water Management Data for the Danube River Basin

A reliable basin-scale model depends on reliable and compatible data. One of the major strands of DWB therefore focused on establishing common practices for collecting, preparing, storing and sharing information. One of the key foundations of the Danube Water Balance

project is the availability of reliable and harmonized data. The project therefore established a Central Data Storage (CDS) to collect and organize relevant environmental, hydrological, meteorological and water management data from across the Danube River Basin.
The repository brings together both open-access global and regional datasets and national data provided by the project partners. While global and regional datasets form the main input for the basin-wide and sub-basin modelling, national datasets provide additional information needed to represent local environmental conditions and, in particular, existing water management infrastructure and features. They also support the calibration and improvement of the water balance model.
A common approach was developed for collecting and preparing national datasets. All partner countries committed to provide relevant national data, which were prepared according to agreed content, formatting and naming requirements. This common approach helped to improve the consistency and comparability of the datasets and reduced the need for individual processing solutions when using the data in the project's modelling and post-processing workflows.

The collected national data are organized into six main thematic groups, complemented by a dedicated section for meteorological station data. Each dataset is accompanied by metadata describing the content and relevant information about the data. This makes it easier for users to understand what data are available, where they originate from and how they can be used.
The repository also reflects the different access conditions of national datasets. While many datasets are openly available, some national information is subject to restrictions. These include data that can only be used for non-commercial purposes and data restricted to internal project use. The access conditions are documented together with the relevant datasets.
Beyond the input data, the CDS also contains important modelling resources. The repository provides access to the latest simulation results for the Danube River Basin and the four pilot sub-basins, as well as calibration results. Users can access different water balance variables, such as discharge, precipitation, evapotranspiration, runoff, snowmelt and total water storage. The available outputs can be provided at different temporal resolutions and in several commonly used data formats.
The calibration results provide an additional level of information on the performance of the model. The calibration approach allows results to be examined for individual sub-catchments, supporting a more detailed assessment of the model across the Danube Basin and in the pilot areas.
The CDS was designed not simply as a storage location, but as an important part of the project's overall data and modelling infrastructure. It provides a common environment in which datasets, model configurations, modelling results and related documentation can be organized and accessed in a consistent way.
At the same time, the project recognized that different types of resources require different long-term storage solutions. Large input and output datasets require substantial storage capacity, while modelling scripts and software tools benefit from platforms designed for version control and continued development. For this reason, the long-term concept is based on a decentralized repository structure, with different types of resources stored in appropriate environments and linked through documentation and guidance.
The CDS currently operates under the LP's FTP server at the webpage: http://danubewb.com



Flowchart of Activities related to the establishment of the Central Data Storage

Joint Data Management Strategy

The Joint Data Management Strategy (DWB-DMS) takes the project's data work beyond the establishment of a repository. Its long-term objective is to provide a harmonised and sustainable framework for collecting, managing and exchanging the datasets needed for basin-wide water balance modelling, while improving their accessibility, quality and interoperability. The strategy connects data management directly to the practical requirements of the Danube River Basin Water Balance Model (DRB-WBM) and to future joint water-management applications.

A central principle of the DWB-DMS is that data sharing should become more transparent and reproducible while respecting legitimate national and institutional restrictions. The strategy therefore proposes a tiered access approach, distinguishing open datasets from datasets available under non-commercial or internal conditions. It also recommends a living inventory recording dataset types, data owners, institutional contact points, temporal coverage, quality status and access conditions. Standardised templates, minimum metadata, quality-control procedures and reproducible versioning are intended to make datasets easier to discover, compare and reuse.

The strategy also defines responsibilities across the data life cycle. National data providers remain responsible for validating their datasets, while the model and data-management functions are expected to document harmonisation and quality-control procedures and maintain reproducible processing workflows. In this way, each model run can be linked to the relevant input-data version, processing steps and quality status, strengthening traceability and confidence in the resulting analyses.

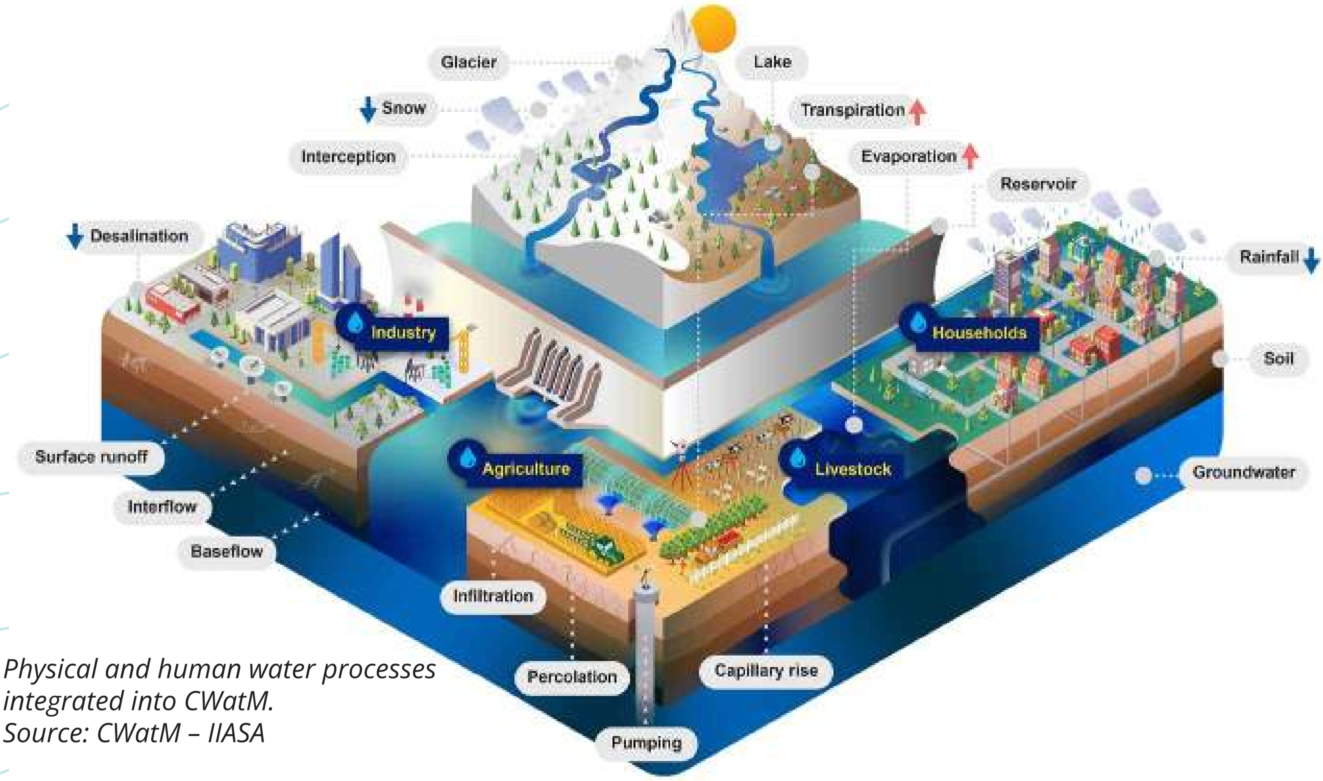
Importantly, the Central Data Storage established by DWB is considered an intermediate, practical solution rather than the final institutional destination for basin-wide data management. The strategy proposes a phased implementation pathway: consolidation of the repository and metadata rules during the project; strengthening harmonisation and priority data gaps in the short term; gradual institutionalization and alignment with existing Danube cooperation mechanisms in the medium term; and, in the longer term and subject to appropriate agreements, development towards more operational and automated data exchange.

The relationship with ICPDR and DanubeHIS is therefore presented as a potential pathway rather than an existing commitment. The strategy envisages possible future steps such as establishing an interface between DanubeHIS and the DRB-WBM, defining a reference set of monitoring stations, and exploring the controlled hosting or exchange of selected validated datasets. Such developments would require further technical work, multilateral agreements and clear institutional responsibilities.

A basin-wide water balance model

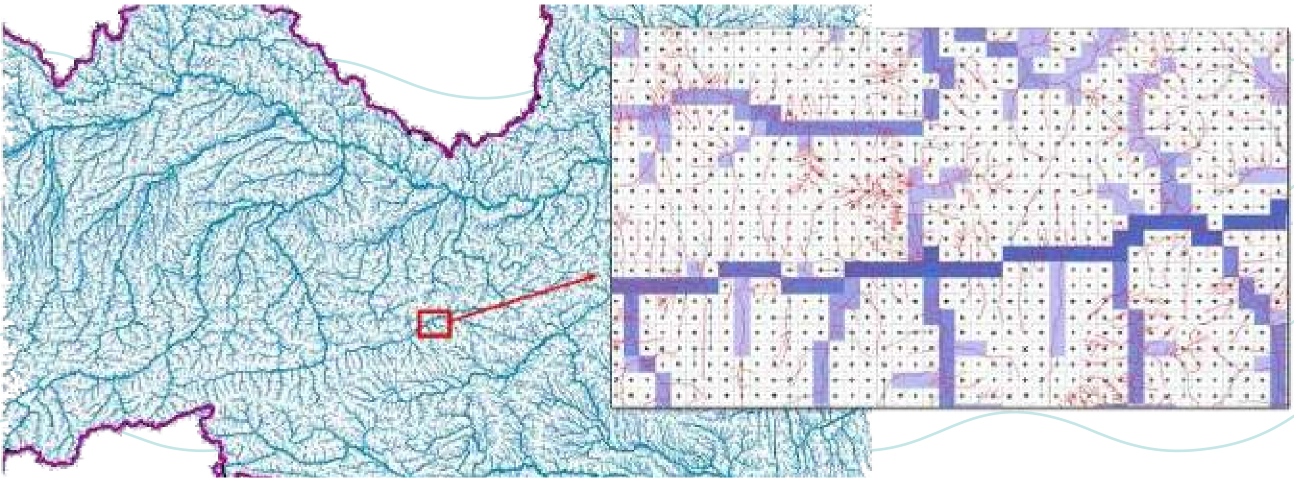
To overcome the historical limitations of fragmented national calculations, the **Danube Water Balance** project adopted an open-source, flexible, and modular modeling core: the **Community Water Model (CWatM)**, developed by the International Institute for Applied Systems Analysis (IIASA).

CWatM is a spatial distributed hydrological model. For the Danube and the pilot basins a spatial resolution of 1 arcmin (~1.8 km x 1.3 km = ~2.4 km2) was chosen. As projection WGS84 EPSG:4326 (lat/lon) is used. This resolution and projection are the same as the European Flood Awareness System (EFAS) as part of the Copernicus emergency management service (https://www.copernicus.eu/en/european-flood-awareness-system). Using the same resolution for the Danube Water Balance and EFAS simplifies the interaction and the exchange of knowledge and data between these two applications of hydrological models.



Physical and human water processes integrated into CWatM.
Source: CWatM – IIASA

CWatM uses a sub-spatial resolution for elevation distribution inside a 1' grid cell (e.g., for calculating the distribution between snow and rainfall) and a sub-spatial resolution for land cover. For each 1' grid-cell, the fraction of six land cover classes is used. Discharge is calculated by using a routing scheme on a river network connection of each of the ~330000 grid cells of the Danube basin. For evaluating performance and disseminating results, it is useful to look at basins that are≥ 200km (around 80 cells). Output of the model can be at a maximum temporal resolution of one day, but CWatM can aggregate on a lower temporal resolution like monthly or annual values for every output variable without postprocessing scripts. Output variables can be any of the ~700 variables the model is using. The more common flux variables are discharge, total runoff, surface runoff, groundwater recharge, total actual evaporation and the more common state variables are water storage in snow, vegetation, different soil compartments, groundwater, rivers and lakes/reservoirs. However, not-so-common variables of the model can be produced like e.g. surface runoff from forested areas, soil percolation from irrigated areas from the second to the third soil compartment, fraction of irrigated areas of each cell etc.
The Model is stored on Github https://github.com/iiasa/CWatM/tree/develop
The main model on Github is programmed in Python with some modules programmed in C++ for faster computation. A description of the model is given in https://cwatm.iiasa.ac.at/. The source code is explained for each module in https://cwatm.iiasa.ac.at/sourcecode.html#source-code.



River network on 1 arcmin. Using DEM and existing river network maps, but manual correction with country data (e.g. Austria: Gewässernetz)

The offline tutorials can be found here: https://github.com/iiasa/CWatM/tree/develop/Tutorials/General

Danube-specific tutorials

For the Danube, we have our own tutorial. It is produced in the framework of the Interreg Danube project: Danube Water Balance 2024-2026.

https://github.com/iiasa/CWatM/tree/develop/Tutorials/Danube

Pilot action testing

To refine the basin-wide setup, the model framework was rigorously tested across four selected transboundary sub-basins representing diverse hydrological regimes:
1. Morava Basin (Czechia, Slovakia, Austria) – High agricultural water pressure and shared alluvial aquifers.
2. Tisa Basin (Hungary, Slovakia, Romania, Serbia, Ukraine) – Highly sensitive to extreme drought events and low-flow dynamics.
3. Upper Sava Basin (Slovenia, Croatia) – Alpine hydrological regime with significant seasonal snowmelt influence.
4. Drina Basin (Serbia, Bosnia and Herzegovina) – Complex topography with heavy hydropower regulation.

Most importantly, the pilot experience helped move the project beyond the question of whether a common water balance model can be operated across national borders. It highlighted how model outputs can be connected to practical water-management questions. Experience from the Tisza and Drina pilots, for example, contributed to recommendations concerning abstraction control, reservoir management, environmental flow requirements, sectoral water demands, climate scenarios and stakeholder involvement. These lessons provide a foundation for further development of the modelling framework towards a more comprehensive water-management tool.

Across all four pilots, the work demonstrated the added value of combining a shared methodology with local expertise. Calibration, validation, scenario analysis and interpretation were carried out in cooperation between modelling specialists and responsible pilot teams. This helped reveal differences in data availability, hydrological processes, water-use pressures and management needs that would not be visible from a purely basin-wide analysis.

Upper Sava – The Upper Sava pilot represents an Alpine-to-lowland and karst-influenced environment, where snow-related processes and seasonal water availability are particularly relevant. The CWatM-based assessment showed that future hydrological responses are spatially variable and sensitive to the selected climate modelling chain. The pilot therefore provided a useful example of combining a common modelling method with basin-specific knowledge when interpreting climate impacts in a complex transboundary setting.

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Upper Sava Pilot area

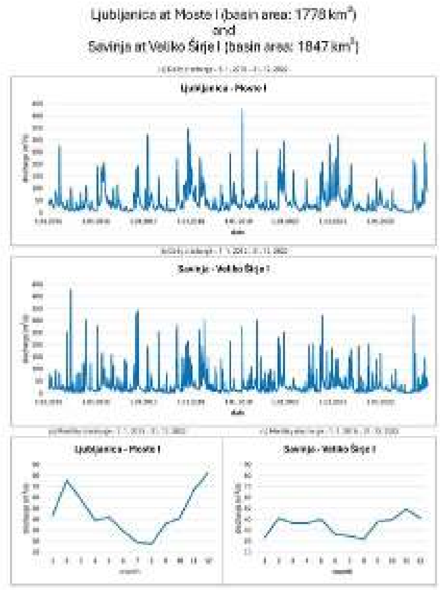
Points

Pilot area: 12,328 km² - 1.5% of Danube River Basin,

Pilot partners: Slovenia ARSO (Slovenian Environment Agency) and Croatia Vode (Croatian Waters),

29 hydrological monitoring stations,

The Upper Sava pilot area covers 12,328 km², which represents approximately 1.5% of the entire Danube River Basin. It covers areas in both Slovenia and Croatia and is jointly managed by ARSO (Slovenian Environment Agency) and HR Vode (Croatian Waters). The map highlights 29 monitoring stations were used for model calibration and validation.

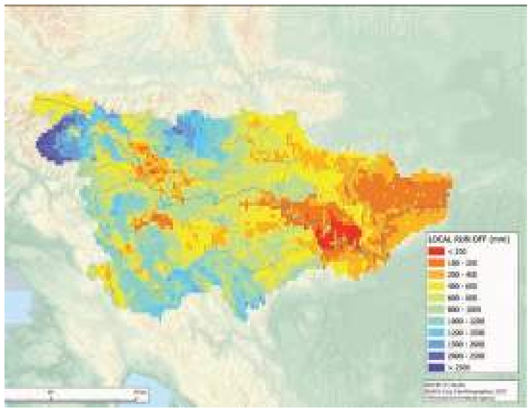


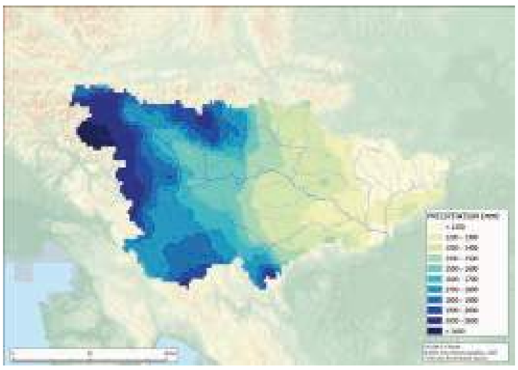
Points

Heterogenic pilot area: karstic Watershed Ljubljanica (station Moste I) and surface fluvial Watershed Savinja (station Veliko Širje I),

Similar size of catchments but different hydrological conditions between karst and non-karst environments.

The graph and the map show two stations where discharge is measured. One station is located on the Ljubljanica River (Moste I), and the other on the Savinja River (Veliko Širje I). The Ljubljanica catchment is karstic, while the Savinja catchment is non-karstic. Since the two catchments are similar in size, they can be compared in terms of hydrological conditions in karstic and non-karstic areas.
The amount of precipitation in the Savinja catchment is on average about 300 mm lower than in the Ljubljanica catchment. However, due to its non-karstic area, the Savinja has more pronounced discharge peaks, as most of the rainfall quickly runs off over the surface. In contrast, in the Ljubljanica catchment, precipitation infiltrates into the subsurface and flows underground to springs in the shallow karst area.





Points

CWatM model run for average annual precipitation (1991–2020),

Highest precipitation in the northwest (>2600 mm/year),

Precipitation decreases gradually toward the east,

Lowest precipitation in the east (<1200 mm/year).

The CWatM model was run using for average annual precipitation data in the period 1991–2020. The highest precipitation values occur in the northwestern part of the pilot area, where annual precipitation exceeds 2600 mm. Mowing eastward, the average precipitation gradually decreases, with the lowest values recorder in the eastern part of the area, where annual precipitation is less than 1200 mm.

Points

Average annual local runoff 1991–2020,

The highest runoff values in the northwestern part (>2600 mm),

Precipitation contributes to local runoff,

The average annual local runoff decreases towards the east,

The lowest values (< 100 mm) in the southeastern part of the pilot area.

The average annual local runoff in the period 1991–2020, as calculated by the CWatM model, is highest (>2600 mm), in the northwestern part of the pilot area, corresponding to areas with the greatest precipitation, where a large portion of precipitation contributes to local runoff. Moving eastward, the average annual runoff gradually decreases, with the lowest values—below 100 mm—recorded in the southeastern part of the area.

Morava – The Morava pilot covers a contrasting lowland-to-upland setting and was used to assess climate-related changes within the common Danube modelling framework. The analysis demonstrated how the same approach can be applied across different hydroclimatic contexts while revealing substantial spatial variability in projected responses. It contributed to the cross-basin understanding of changes in runoff, water availability and low-flow behaviour, and highlighted the need for careful interpretation where climate modelling chains produce different signals.

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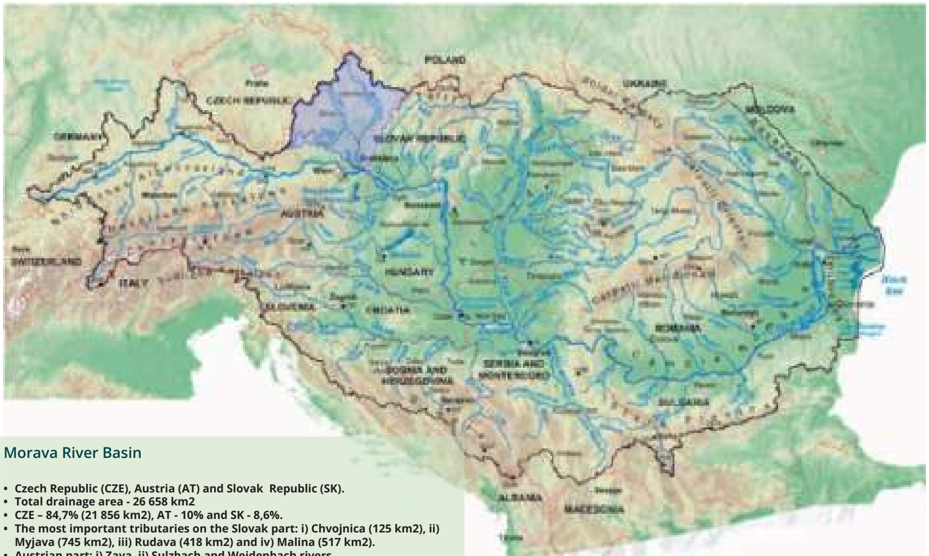
Pilot study – Morava River basin

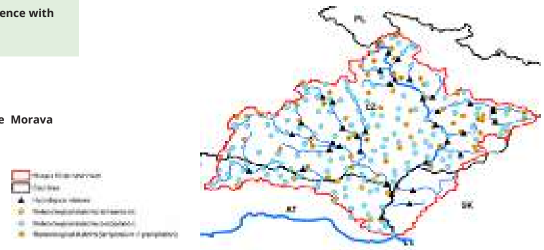


Morava River Basin

- Czech Republic (CZE), Austria (AT) and Slovak Republic (SK).
- Total drainage area - 26 658 km2
- CZE – 84,7% (21 856 km2), AT - 10% and SK - 8,6%.
- The most important tributaries on the Slovak part: i) Chvojnica (125 km2), ii) Myjava (745 km2), iii) Rudava (418 km2) and iv) Malina (517 km2).
- Austrian part: i) Zaya, ii) Sulzbach and Weidenbach rivers.
- The long-term average discharge of the Morava river at the confluence with Danube river is 119 m3.s-1.

Pilot study – Morava River basin

- Network of hydrological and meteorological stations within the Morava River basin.
- Color coded with regard to the observed variable.



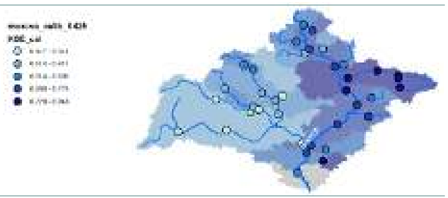
CWatM model: Morava River basin

- Network of hydrological stations within the Morava River basin.
- Subbasins are color coded just to show each of them using this station network.

CWatM Morava River Basin – model calibration

- Calibration results for 37 hydrological stations using KGE.
- These stations were used to calibrate the CWatM.

The slide represents results of Morava River Basin – model calibration. Each point is hydrometric profile and color describe result of Kling–Gupta efficiency (KGE) score, see in legend.



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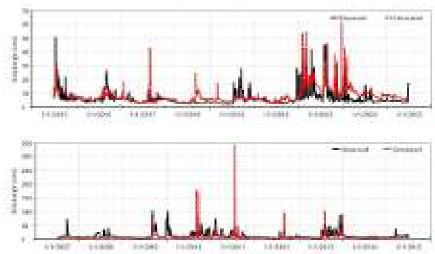
CWatM Morava River Basin – results 1

- Calibration and validation time series for the worst KGE result of calibration G0045 – VD Znojmo.

In each charts red line is simulated time series of discharge and black line is observed time series of discharges.



CWatM Morava River Basin – results 2

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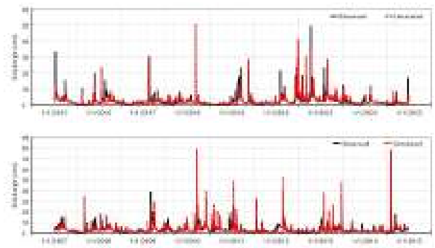
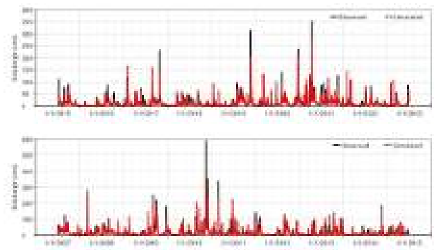


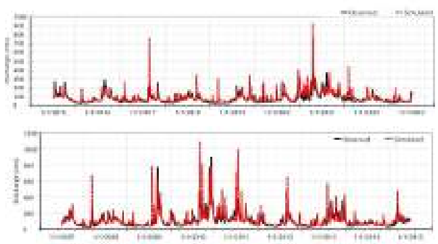
CWatM Morava River Basin – results 3

The slide represents best KGE results/score for hydrometric profile G0020 - Dluhonice.



CWatM Morava River Basin – results 4

Representing last station within the Morava River basin near to confluence with Danube G0060 – Záhorská Ves. In each charts red line is simulated time series of discharge and black line is observed time series of discharges.



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Morava – The Morava pilot covers a contrasting lowland-to-upland setting and was used to assess climate-related changes within the common Danube modelling framework. The analysis demonstrated how the same approach can be applied across different hydroclimatic contexts while revealing substantial spatial variability in projected responses. It contributed to the cross-basin understanding of changes in runoff, water availability and low-flow behaviour, and highlighted the need for careful interpretation where climate modelling chains produce different signals.

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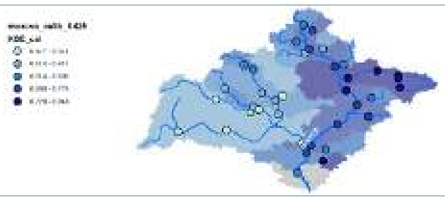

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CWatM Morava River Basin – results 1

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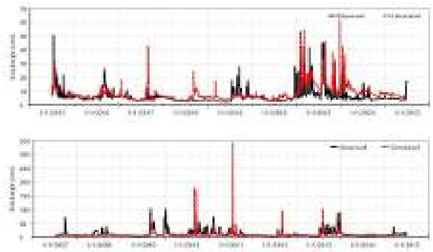
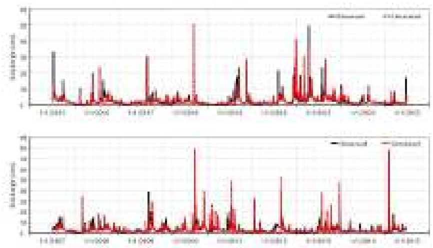


CWatM Morava River Basin – results 2

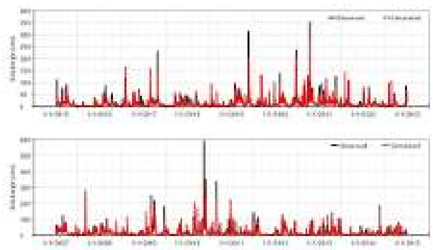
- Calibration and validation time series for the worst KGE result of calibration G0045 – VD Znojmo.

In each charts red line is simulated time series of discharge and black line is observed time series of discharges.



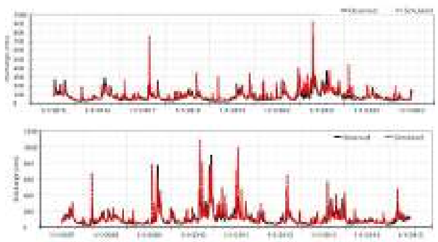
CWatM Morava River Basin – results 3

The slide represents best KGE results/score for hydrometric profile G0020 - Dluhonice.



CWatM Morava River Basin – results 4

Representing last station within the Morava River basin near to confluence with Danube G0060 – Záhorská Ves. In each charts red line is simulated time series of discharge and black line is observed time series of discharges.



Drina – The Drina pilot represents a predominantly mountainous transboundary basin with distinctive geological and hydrological characteristics. The CWatM application was recalibrated for the basin and used to assess a range of climate modelling chains and future conditions. The analysis highlighted the importance of basin-specific processes and uncertainty when interpreting future hydrological changes, and provided experience for connecting water-balance information with future transboundary management, including reservoir and hydropower-related questions.

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Drina river basin

General description of the subbasins e.g. whare, how much precipitation on average, how much discharge, countries, main sub-basins. Geological, geomorphological features etc. (1/2 page each pilot)

The Drina River Basin (DRB) spans an area of approximately 20,000 km², distributed almost evenly among three riparian countries: namely, Montenegro (31.5%), Bosnia and Herzegovina (37%), and Serbia (30.5%), while less than 1% of the basin area is located in Albania. The river's main course extends 335 km, beginning at the confluence of the Piva and Tara rivers on the border between Montenegro and Bosnia and Herzegovina in the south, to the confluence with the Sava River in the north. The hydrographic network is well-developed, with key tributaries including the Tara, Piva, Lim, Ćehotina, Prača, Rzav, Uvac, and Drinjača rivers. The basin elevation ranges between 75.4 m a.s.l. at the mouth to more than 2,500 m a.s.l. on the highest mountains (Prokletije Mountain 2,694 m a.s.l.), with the mean elevation of 961.6 m a.s.l.

Location of the Drina River Basin

The average annual precipitation in the basin is approximately 1,100 mm, and the discharge at the confluence with the Sava River is around 380-400 m³/s. High precipitation depths in the mountainous southern regions of about 3,000 mm per year result in significantly higher specific runoff (approximately 50 L/s per km²) compared to the central (10-15 L/s per km²) and northern areas (2-8 L/s per km²). Notably, around 60% of the total river flow originates in Montenegro.

Special features of the subbasins (e.g. reservoir, karstic, which some water transfer).

The Drina River Basin, with its abundant water resources, is primarily utilized for hydroelectric power generation. To facilitate hydropower production, numerous dams and reservoirs have been constructed, many with large storage capacities, such as Zvornik, Bajina Bašta, and Višegrad on the Drina River; Piva (Mratinje) on the Piva River; Potpeć on the Lim River; Uvac, Kokin Brod, and Radoinja on the Uvac River; and Otilovići on the Ćehotina River. These reservoirs, all constructed before 1990, play a crucial role in regulating the water regime.

Other water uses, including public water supply, industrial consumption, and agricultural irrigation in the lower parts of the basin, have minimal impact on the overall water balance. This is primarily because most of the water is returned to the river after use, and consumptive losses from irrigation are relatively small.

Another feature of the basin to be accounted for in the model calibration and evaluation are karst formations of considerable depth in the upper parts of the basin. In this part of the basin it is nearly impossible to delineate the boundary between the Black Sea and Adriatic Sea basins, or to accurately define the catchment areas that contribute water to rivers flowing into the Drina River, and subsequently towards the Sava River. In the Drina River Basin there are 43 groundwater bodies (GWB), of which 20 GWB are in completely the karst aquifer.

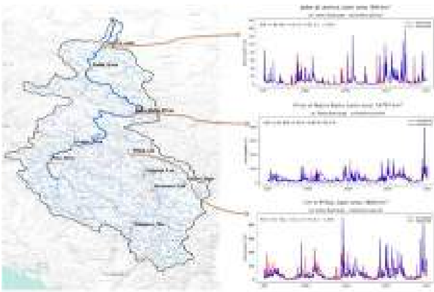
Danube Water Balance project activities

During Danube Water Balance project project representatives of PWMC Srbijavode (PP13, RS) organized several meetings with projects partners from Serbia (RS) and Bosnia (BA): Institute for Water Management, PP9, BA), University of Sarajevo (PP10, BA), University of Novi Sad Faculty of Agriculture (PP11, RS), PP12 Jaroslav Cerni Water Institute (PP12, RS) and with associated partners from Serbia, Bosnia and Montenegro: Sava River Watershed Agency (ASP6, BA), Ministry of Agriculture, Forestry and Water Management (ASP13, ME), Republic Hydrometeorological Service of Serbia (ASP10, RS), Public Water Management Company of Vojvodine (ASP11, RS).

Main goal of those meetings was to comment template for hydrology, climatology, hydrogeology, spatial data, as well as data related to water management data and to collecting needed data.

After that, the model was calibrated at 77 stations in the Sava river basin, 10 of which are in the Drina sub-basin:

Overview of the collected datasets



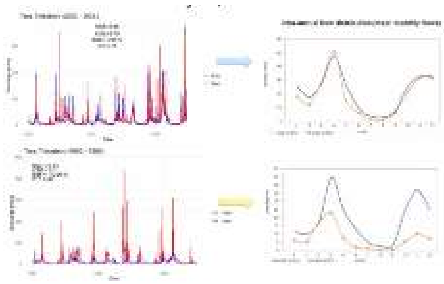
Results of model calibration

Simulation periods:
1990-1995 (dry period)
2000-2005 (wet period)

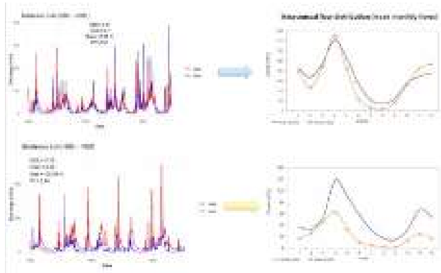
Simulation was performed for 5 selected locations: Radalj, Bajina Bašta and Goražde on the main course of Drina river, Brodarevo on one of major tributaries Lim river and Trebaljevo on river Tara, one of constituent rivers in the headwater part of the basin. Simulation results were compared with the observed flow values for selected stations. Model version does not include data collected

Results interpretation:
Visual inspection (volume, runoff dynamics, seasonality)
Numerical performance indicators: KGE (Kling-Gupta Efficiency), NSE (Nash-Sutcliff Efficiency), B (Bias), R2 (Coefficient of Determination)
Intra-annual flow distribution charts

Results overview – Trebaljevo, Tara

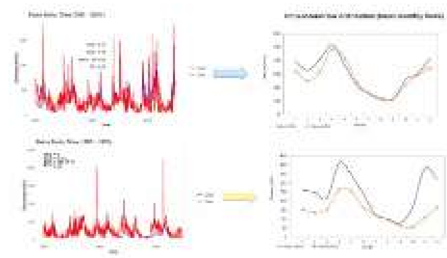


Results overview – Trebaljevo, Tara



Results overview – Goražde, Drina

Results overview – Trebaljevo, Tara



GENERAL DIRECTORATE OF WATER MANAGEMENT

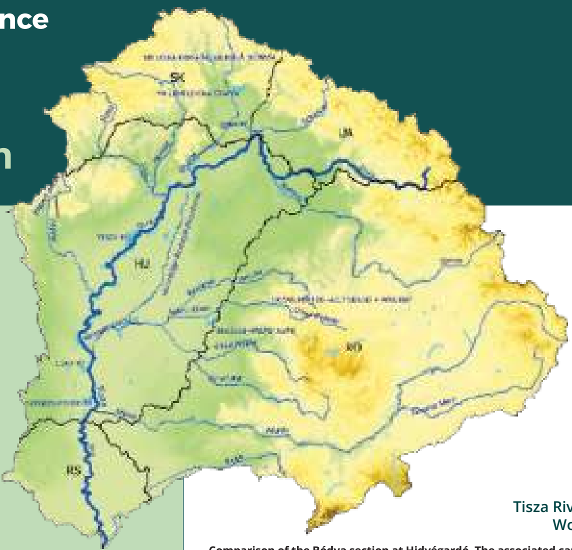
Tisza – The Tisza is the largest of the four pilot sub-basins and represents an important case for transboundary water-balance assessment, involving five riparian countries and strong interactions between surface water, groundwater and extensive lowland areas. The pilot was used for basin-scale modelling and detailed climate impact assessment, with particular attention to future water availability and low-flow conditions. The work also provided a basis for discussing how water-demand assumptions, reservoir operation and planned water-management interventions can influence future water availability.

Interreg
Danube Region

Co-funded by
the European Union

Danube Water Balance

Tisza River Basin

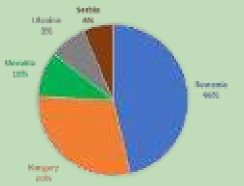


Tisza River Basin – characteristics

Karst areas with sinkholes and springs

Mountainous areas with rapid accumulation

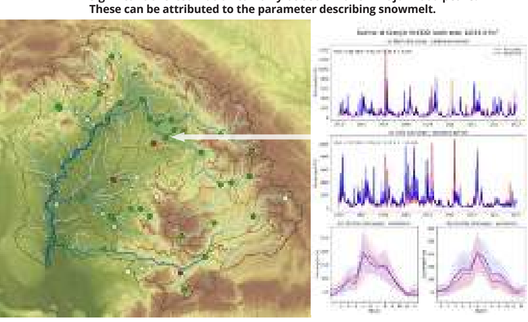
Low-lying region with water levels and groundwater upwelling



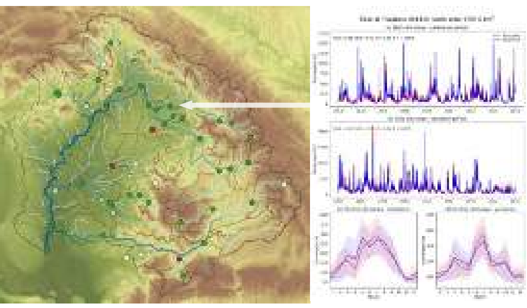
Sum: 156 869 km2

Tisza River Basin – Work results

The figure shows the results obtained for the water gauge at Csenger on the Szamos River. The associated catchment area is 15,283 km². The calculated water yields correspond well to the measured data: the model efficiency is high (KGE, NSE) and the volumetric error (B) is acceptable.
Significant overestimation can only be seen in a few major flood peaks. These can be attributed to the parameter describing snowmelt.

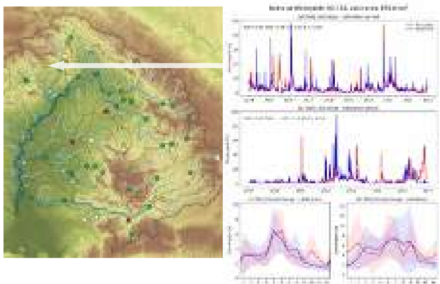


Comparison of the Tisza border section at Tiszabecs. The associated catchment area is 9,707 km². The calculated water yields fit the measured data perfectly: the model efficiency (KGE, NSE) is outstanding, and the volumetric error (B) is low. There are no significant underestimations or overestimations.

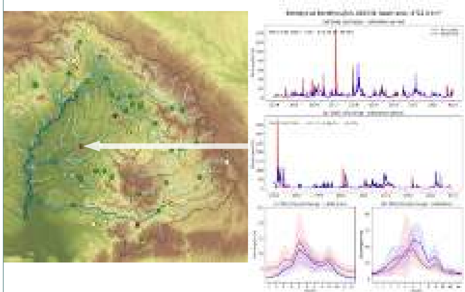


Tisza River Basin – Work results

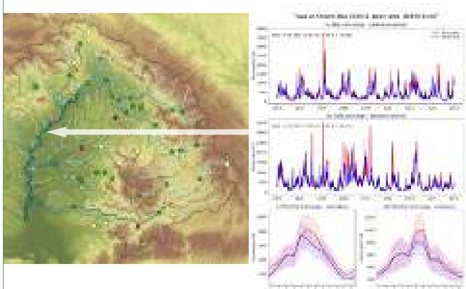
Comparison of the Bódva section at Hidvégardó. The associated catchment area is 875 km². The calculated water flows do not match the measured data very well: model efficiency (KGE, NSE) is low, and the volumetric error (B) is moderate. The model consistently underestimates the water flow during low water periods, while it also inaccurately estimates the peak flow and timing of flood waves. This is mainly due to the small catchment area.



Comparison for the Berettyó section in Berettyóújfalu. The associated catchment area is 3712 km². The calculated water flows do not correspond well with the measured data: model efficiency (KGE, NSE) is lowest in this gauge section, the volumetric error (B) is high, and the model overestimates during the calibration period and significantly underestimates during validation. This phenomenon is due to the highly regulated nature of the watercourse system.

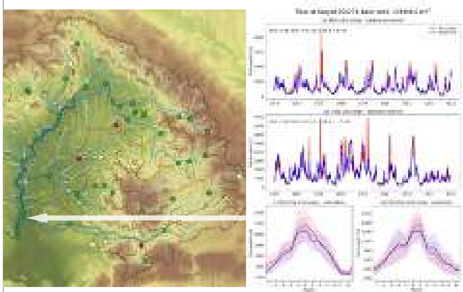


Comparison for the lower section of the Tisza in Kisköre. The associated catchment area is 65,670 km². The calculated water flows fit the measured data well: the model efficiency (KGE, NSE) is adequate, and the volumetric error (B) is moderate. The model correctly simulates the timing of flood peaks, but consistently overestimates the water flow. This is because the incorporation of the flood control operation of the Kisköre dam into the model is still in progress.

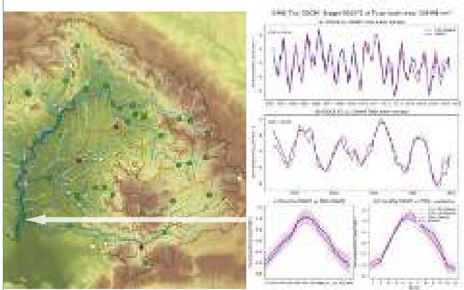


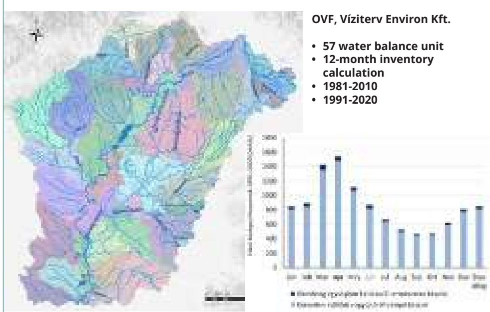
Tisza River Basin – Work results

Comparison for the Szeged section of the Tisza. The associated catchment area is 138,408 km². The calculated water flows fit the measured data well: the model efficiency (KGE, NSE) is high, and the volumetric error (B) is medium/low. The model correctly simulates the timing of flood peaks, but consistently overestimates the water flow. This is because the incorporation of the flood control operation of the Kisköre dam into the model is still in progress.



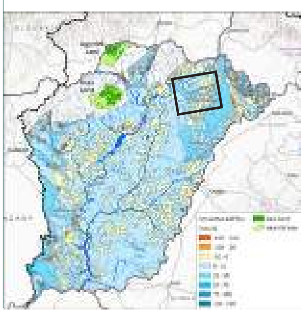
Comparison of sub-surface water reserves in the catchment area extending to the Szeged section of the Tisza River (138,408 km²). The measured data show the gravimetrically estimated change in sub-surface reserves from the GRACE satellite mission, while the calculated data are the CWatM-simulated equivalents. The agreement can be considered adequate in both the calibration and validation periods.





OVF, Víziterv Environ Kft.

- **57 water balance unit**
- **12-month inventory calculation**
- **1981-2010**
- **1991-2020**



Vertical groundwater flows :

Significant recharge
Evaporation at the upflow sections
Resulting in lower base flow, than if it was recharge

Karst:

[m3/day]	Bükk	Aggtelek
Recharge	120.000	26.000
Water abstraction	43.000	1.500

Empty spaces: cracked rocks

GENERAL DIRECTORATE OF WATER MANAGEMENT

Although the four pilot areas differ considerably, they were assessed using a common modelling architecture. The CWatM model was calibrated and validated against available observations, prepared with harmonised input datasets and used to simulate historical and future conditions. This common basis enabled comparison across contrasting hydrological settings while allowing each pilot team to retain indicators and analyses reflecting its own management priorities.

From model outputs to usable information: WebGIS

Activity regarding Deliverable 3.6.1. focused on developing the tool for interpreting and visualizing the calculated water balance model results, with the aim of providing user-friendly and accessible means of understanding and disseminating the water balance components. The activity developed universal tool for mapping and charting the calculated water balance components, enhanced with spatiotemporal statistics of selected variables. This tool is developed using commonly used programming language Python.

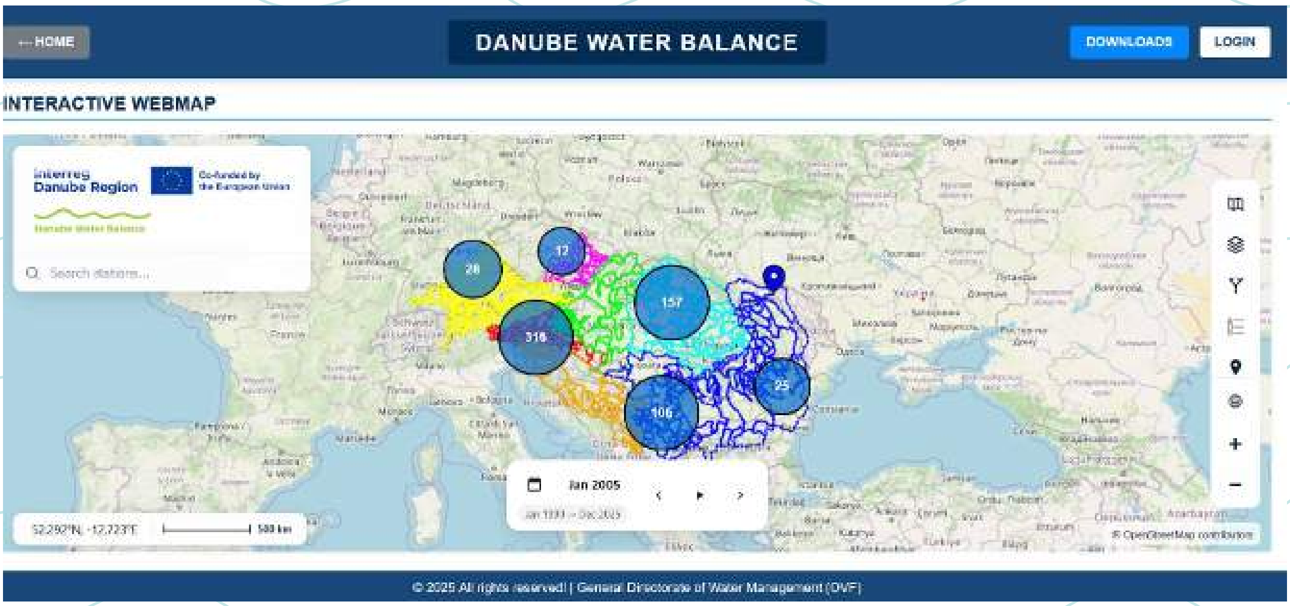
First, beta version was available in period 3 while final version of the tool will be integrated into a Toolbox (Output 3.3). The Toolbox will serve as a comprehensive resource that incorporates various functionalities for data interpretation and visualization. By integrating these tools into the Toolbox, stakeholders will have a centralized platform to access and utilize these resources efficiently.

The mapping and charting capabilities of the tool will enable stakeholders to visualize the spatial and temporal patterns of the calculated water balance components. This visual representation will enhance the understanding of the data and facilitate the identification of trends, anomalies, and patterns in the water balance variables. Additionally, spatiotemporal statistics will provide further insights and analysis of the selected variables, allowing stakeholders to derive meaningful conclusions from the model results.

Tool for the Interpretation and Visualization of the DRB-WBM results will contribute to effective knowledge dissemination and engagement of stakeholders. Moreover, making the tool available to the public will promote transparency, awareness, and public understanding of water balance components and their implications.
UNSFA, as the responsible partner for Activity 3.6, coordinated a structured development process combining technical implementation with continuous partner engagement. This process was initiated through a series of meetings, brainstorming sessions, and bilateral exchanges with project partners and associated stakeholders.

The platform is the central access point through which project partners and stakeholders reach the project's data, information and results, and it hosts the interactive tool used to visualise the model outputs at , explore the underlying spatial and temporal data, interpret the generated results, and support stakeholder assessment and decision-making at http://danubewb.com/webmap.php.

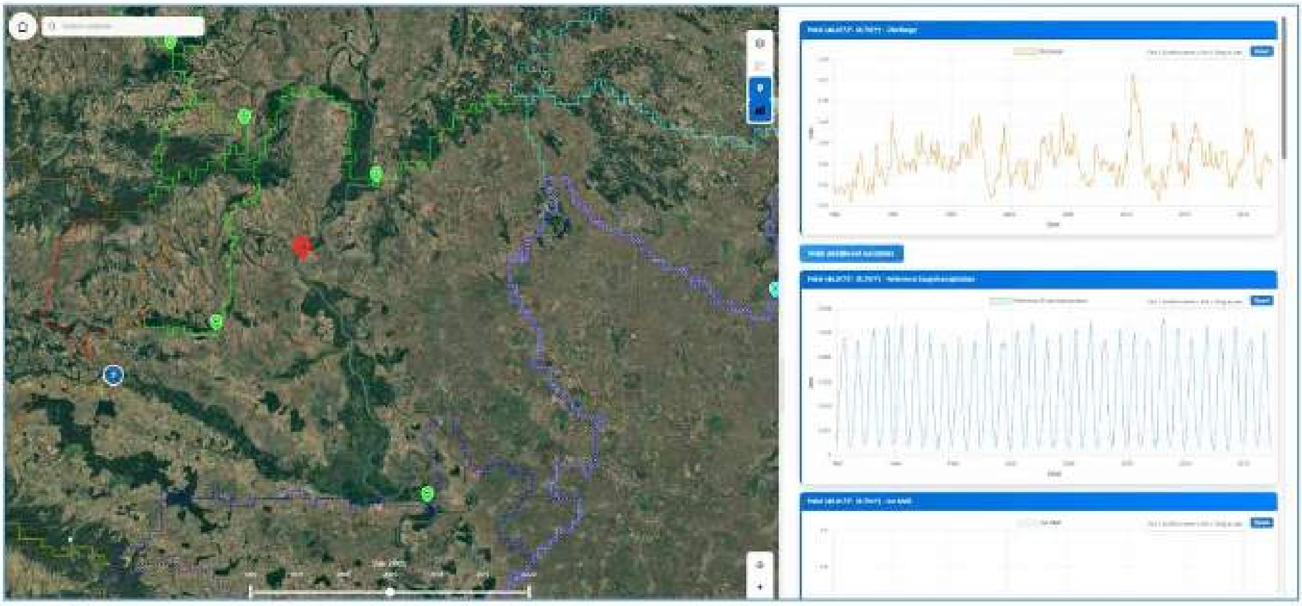
The GIS module provides an interactive web map that displays monitoring stations, subbasin boundaries and gridded monthly NetCDF datasets for key variables such as rain fall, run off, snow melt, evapotranspiration, discharge, etc. Users work with these datasets as time-enabled thematic layers and generate monthly time-series charts for each calibration station and each subbasin, which sup-



ports detailed inspection of temporal patterns and trends. In addition, the GIS view exposes a point-based analysis tool that extracts a complete monthly time series for any arbitrary map location (single pixel) derived directly from the underlying NetCDF files. The interface includes a layer panel for selecting GeoServer layers, a global time slider for controlling the active time window, a search box for station and subbasin lookup, clustering of station markers and rich hover and click interactions. Raster layers are served from GeoServer as time-enabled WMS layers. Users can toggle each layer, inspect color legends, animate the temporal evolution with a play button and view detailed charts and tables in side panels.

UNSFA developed the beta version as a local geo-portal, which can be launched via a simple Python script and accessed through a standard web browser. The tool is designed to operate on local machines, ensuring ease of deployment and independence from external servers during the testing phase.
A key technical advancement introduced in this activity is the conversion of CWatM NetCDF outputs into GeoTIFF raster files. This additional processing step significantly improves usability, as GeoTIFFs are widely supported and allow efficient handling of spatial raster data. Each NetCDF file is converted into a series of daily GeoTIFF layers, which are subsequently ingested into the geo-portal.

All map rendering and chart extraction are powered by a full-stack architecture that combines a React frontend with interactive mapping and charting components, a NestJS (Node.js) backend with a spatially enabled PostgreSQL/PostGIS database, and high-performance Python modules for NetCDF and Parquet processing. This technology stack is optimized to handle large volumes of environmental data (covering 645 monitoring stations and 645 subbasins) and to deliver maps and charts within a few seconds, while using robust open-source frameworks that keep the system fast, scalable and maintainable.



The DWB WebGIS provides an interactive environment for exploring hydrological modelling outputs, spatial and temporal patterns, monitoring stations and sub-basin information. It is intended to make model results more accessible to water-resource managers, researchers and other stakeholders.

The platform was refined through demonstrations and feedback collected during project meetings and stakeholder events. Its architecture was developed to handle environmental datasets and support long-term scalability. Together with the project's data repository, the WebGIS creates a bridge between the technical data and the practical interpretation of model results.
A detailed description of how to use the tool is available in the document Deliverable 3.6.1 - Tools for the Interpretation and Visualization of the DRBWBM Results.

Capacity building and stakeholder engagement

Technical tools alone cannot create transboundary cooperation. DWB therefore placed strong emphasis on capacity building, stakeholder dialogue and knowledge transfer. The partnership organised international and national stakeholder workshops, trainings, partner meetings and dissemination activities across the Danube Region. The Sarajevo workshop was a key capacity-building event, combining technical presentations, an advanced CWatM session for project partners and opportunities for stakeholder feedback.

Training materials and guidance were harmonised and updated to support self-learning and the longer-term use of CWatM, the WebGIS platform and related tools. The materials are intended to make the project's technical knowledge available beyond the organisations directly involved in implementation.

Stakeholder engagement also took place at pilot level. In the Tisza Basin, for example, the project organised a stakeholder workshop in Szolnok, bringing together water-management institutions and international participants to discuss the project's results, modelling approach, WebGIS and possible future cooperation.

The project also strengthened its links with the ICPDR, which provided an important strategic context for the development of the data management approach, stakeholder engagement and future application of the modelling results.

Main project outputs

The DWB project has produced a portfolio of interlinked outputs. Rather than treating each deliverable as a standalone document, the project results should be understood as parts of a common information and knowledge

Result area	Key outputs / products	What it enables
Data management	Central Data Storage; data collection and harmonisation procedures; Joint Data Management Strategy.	More consistent, transparent and reusable datasets for transboundary modelling.
Water balance modelling	Basin-scale CWatM application; calibrated and validated pilot applications; modelling documentation.	Consistent assessment of water balance processes across the Danube Basin.
Climate assessment	Climate impact analyses and future scenarios for pilot areas.	Exploration of future water availability, particularly under low-flow and drought conditions.
Interpretation and visualisation	DWB WebGIS and supporting visualisation tools.	Accessible exploration of model outputs by non-specialist users.
Capacity building	Guidelines, training materials, workshops and technical sessions.	Knowledge transfer and longer-term uptake of the modelling approach.
Stakeholder engagement	Stakeholder workshops, feedback and capacity-building outputs.	Connection of technical results with user needs and management questions.
Future development	Recommendations for a water-management-oriented modelling framework and continuation concept.	A pathway towards stronger integration of modelling with operational water management.